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Overview of the legislation of DC injection in the network for low voltage small grid-connected PV systems in Spain and other countries

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Abstract

In recent decades there has been an increasing interest in the use of low voltage small grid-connected photovoltaic (PV) systems, conditioned by new incentives from distinct countries. An essential element in those systems is the inverter, that is, the element which converts, in an efficient way, sinusoidal AC current waveform at its output so that it may be connected and synchronized to the utility network. However, that conversion must meet some minimum quality criteria with respect to the harmonics current, DC injection and power factor. Precisely, this work studies the relation of the PV inverter with limits of DC injection in the network, in the AC side. This has been carried out by means of the compilation referring to DC injection for low voltage small grid-connected PV systems exclusively, as well as the international standards and effective legislation in six countries (the USA, Germany, Japan, Spain, Australia and the United Kingdom), where the grid-connected PV industry has experienced remarkable growth in the last 10 years.

Keywords: Low voltage small grid-connected PV systems; Public network; DC injection

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1. Introduction

Energy has been playing a determining role in economic–political–social events occurring in the world as of the second half of 20th century. It is crucial for economic growth and human development, and is fundamental to the quality of our lives. Greater or lesser availability of energy determines the economic development or stagnation of a country. Nevertheless, it was not until in the 1980s that intense legislative activity was carried out in Europe regarding energy, making the relation between the increase of industrial production, energy consumption and environmental protection more evident.

Thus, a White Paper for a Community Strategy and Action Plan, concerning the future of renewable energy in the European Union, was adopted by the European Commission on November 26th, 1997. It defined a strategy and plan of action to promote market penetration of renewable energy sources, with a target of doubling their use by 2010 (from 6% of total consumption in 1996 to 12% in 2010).

At the same time, one of the characteristics of the Spanish energy system is its high degree of dependence on imports. Eighty percent of energy consumed has to come from imported sources. Spain imports approximately 64% of its coal, 99.5% of its oil, and 99.1% of its gas. Moreover, oil accounts for around 50% of Spain's primary energy consumption. Furthermore, on August 26, 2005 the Spanish government approved the new Renewable Energy Plan (*Plan de Energias Renovables*, PER), which supersedes the Renewable Energy Promotion Plan, which dates back to 1999. The overall aim of the new Plan is to make it possible to achieve the target of 12% of Spain's primary energy demand being met from renewable sources by 2010, and to do so it sets more ambitious objectives in those areas that have been successfully carried out and establishes new measures to support technologies that have not yet managed to take off. The total amount of the investment of the Plan in the period 2005–2010 that has been budgeted is €23,598,641. Although in the 1994–2004 period the global consumption of renewable energies grew in Spain by 2700 ktep, by the end of the year 2004 it had achieved only 28.4% of growth anticipated for those energy sources.

In Spain, photovoltaic (PV) power installed increased by 11.7 MW in 2004, which put Spain in third place with respect to total power installed, with 38.69 MW, behind Germany.

The increases forecasted will come, mainly, from the connected PV systems, many of which will be small, less than 5 kW, such as: PV surfaces installed on roofs and existing

facades, PV surfaces integrated into the design and construction of new buildings, small systems…

2. Legal framework of the interconnection to the network

With respect to legislation regarding renewable energy, in the early 1980s Law 82/1980 of December 30th, was passed concerning energy conservation. However, the first PV systems connected to the electrical network in Spain were regulated by Royal Decree 2266/94, in which, for the first time, the special electrical production system was regulated. The major incentive in the electriciy market came from the regulation of the sector. Following that, a new general electricity law, the Spanish Power Act 54/1997, dated November 27th, came into force, in the Electrical Sector [1–4], establishing principles of a new model of operation based on free competition, and likewise, boosting the development of energy in special systems. The pressure of the renewable energy sector conditioned the writing and approval of a new decree that regulated, with more detail, the establishment of forms of generation.

Royal Decree 2818 of 1998 carried out Law 54/1997 in the Electricity Sector with modifications introduced by Law 66/1997 of December 30th regarding fiscal, administrative and corporate measures, promoting the development of facilities under a special legal system through the creation of a favorable framework, without incurring discriminatory situations that could limit free competition while establishing differentiated situations for those energy systems that contribute more efficiently to the above mentioned objectives. For facilities based on renewable or waste energies, this incentive has no time limit, since their environmental benefits must be internalized and, due to their special characteristics and level of technology, their considerable cost does not allow them to compete in the free market. The incentives which are established for renewable energies are such that they will enable their contribution to the Spanish energy demand to be a minimum of 12% in the year 2010. Likewise, it provides an advantageous power rate of up to kWh produced by PV solar facilities connected to the grid. Utilities must buy PV electricity at €0.4/kWh for systems of less than 5 kW and at €0.2/kWh for systems of more than 5 kW. Two years later, the Royal Decree 1663/2000, [5,6] was approved, which is applied to PV installations of nominal power of not more than 100 kVA and whose connection to the distribution grid is carried out in low voltage, i.e., not higher than 1 kV. Later, in the Resolution of May 31st 2001 [7], the model for the type of contract and invoice for this systems was established, Fig. 1. Three years later, Royal Decree 436/2004 amended the previous Royal Decree (2818/1998) so as to fit into the existing general framework supporting renewable energy as set out by the Electricity Act 54/1997, which is still in force. It provides incentives for newly installed capacity of renewable energy sources in one of two ways: (1) Generators which sell their production to a distributor receive a fixed tariff that is defined as a percentage of a regulated tariff. The percentage is established on a technology by technology basis. The reference tariff for 2004 had a value of €0.072/kWh. (2) Generators which sell their electricity on the free market receive the negotiated market price of electricity, an incentive for participating, and a premium, if eligible.

Also, in Spain the electrotechnic Regulation of low voltage is applicable to this sector [9], as well as particular specifications from Communities [10] and of the distributing company [11].

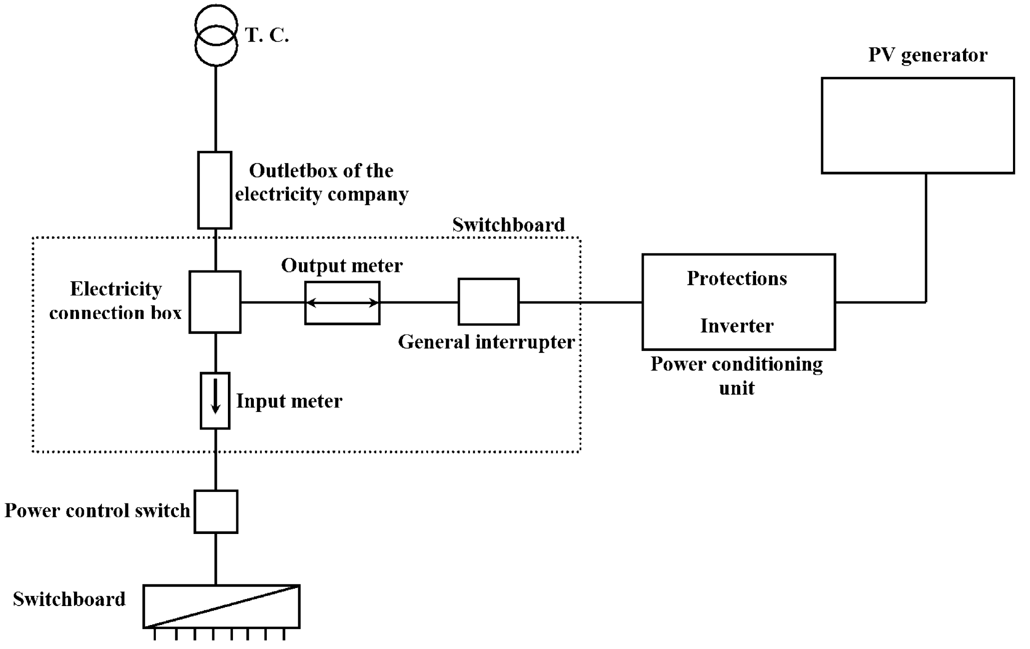

Fig. 1. Schema detailed in the Resolution of May 31st 2001, to be applied to low voltage small grid-connected PV systems connected to the public network, in Spain [7].

3. PV systems connected to the network

Although norm CEI 61727: 1996, [12], proposes a scheme of interconnection of the PV systems, a resolution in Spain exists, [7], of forced compliance which establishes elements for low voltage small grid-connected PV systems. Four elements can be distinguished: PV generator (it generates DC electricity by means of PV modules, from energy generated by the sun); power conditioning unit; control and measuring instruments, among which the energy meter stands out; and, finally, the network.

In this work, we will focus on the preparation of the power unit, and more specifically on DC/AC converters.

In addition, according to the standard IEEE P929, [13], and taking into account their power, the PV grid-connected systems can be classified in the following way: small power systems, up to 10 kW; medium power systems, 10–500 kW; and finally, large power systems, from 500 kW. This work is centered on the PV small power systems.

4. Power conditioning unit

Before connecting the PV system to the public network DC voltage at PV, the generator is converted to a sinusoidal AC current waveform so that it may be connected and synchronized to the utility network. However, this injection must have certain characteristics that allow efficient operation which is safe and compatible with the generator FV. The quality is judged taking into account the following parameters: power

efficiency conversion, power quality (harmonics emission, power factor, interferences generation,...) and safety for humans, equipment and network.

In the aforesaid unit, there are two main elements: the DC/AC converter and the internal protections.

With respect to the DC/AC converter, several concepts can be distinguished. A general classification of the types of inverters could be the following [14]:

Central inverters: They consist of the connection of a PV generator of several hundreds of watts to a single central inverter.

String inverter: The PV plant is divided into several parallel strings. Each of the PV string is assigned to a designated inverter.

Integrated inverter Modules (AC inverter): It is integration of an inverter of such a form that each inverter connects itself to the network.

This investigation has been centered in the inverters belonging to string inverters.

With respect to the interconnection of PV systems, several aspects can be considered: harmonics, overvoltage protection, islanding... and DC injection in network. Indeed, this is the aspect that is developed in this article.

There are numerous potential sources of direct current, namely: power supplies computer, network failures, geomagnetic phenomena, cycloconverters, lighting circuits/dimmers, embedded generators, AC and DC drives,... and PV grid inverters.

Measurements have been performed on some sources. For example, measurements were taken from computer power supplies, [15], monitoring the DC levels. For this purpose, a Laptop 0.04A DC (7.7% of rms current) was measured as well as 0.03A DC (11.2% of rms current) from a Desktop PC. Also, the reference [16] reports 0.34A DC (0.53% of rms current) from a fluorescent lighting load. However, up to now, measurements of DC current injection from a PV grid inverter have not been made. Theoretically, two of the three types of inverter inverters, HF transformer and transformerless inverters, are candidates for DC current injection.

In order to determine the present technology state of inverters a compilation of manufacturers, brands and models has been made for inverters regarding their use in PV systems of direct connection to the electrical network, updated to 2005. All together, there were 46 companies which commercialize network connected inverters. These companies are the following: ACE, Aixcon, ASP, BP/TRACE, Cornegy, DOFMULLER, EAI, ENERGETICA, EXENDIS, FRONIUS, G&H, GUNTERMAN, Hardmeier Elektronik, IGETEAN, Invertomatic, KAKO, KYOCERA, MAGNETEK, MASTERVOLT, NFK ELECTRONICS, PAIRAN, PHILIPS, Phoenixtec, Photoelectric, Satcon, SIEMENS, SIEMENS Siematic, SMA, SOLARFABRIC, Solar Konzept, SolarStocc, Solon, Solutronic, Solwex, Sputnik SUN POWER, SUNSET, Suntechnics SUNWAYS, TOTAL ENERGE, TRACE, UFE, VICTRON, Wurth Solergy and XANTREX.

Among the inverters who belong to the in chain topology, it has been verified that nowadays the market itself is influenced by the type of isolation that it takes. Thus, we can distinguish between the following inverters: those with transformer, of low frequency (LF) and high frequency (HF), and without transformer. The possibility of installing some of these inverters is regulated by legislation emanating from each country, Table 1.

Upon determining the state of the technique of inverters, information has been compiled, Table 2, with respect to the effective norm, referring, exclusively, to the injection of DC, of connected PV systems of low tension to the network, in six of the most representative countries in this field, which are the USA, Germany, Japan, Spain, Australia

Table 1
Isolation transformer requirement in different countries

No require	It depends	Required
Germany	Australia Japan Great Britain USA Spain	Spain

Table 2
Standards which are in Australia, Germany, Great Britain, Japan, Spain and USA, according to permitted DC injection to the network

País	Standares	
USA	IEEE 929–2000 [13]	The PV system should not inject current >0.5% of rated power inverter ground output current into the AC interface under either normal or abnormal operation conditions.
Japan	Technical guideline for the grid interconnection of dispersed power generating systems [17]	DC injection detection device with inverter disable is required for transformerless inverters. Maximum allowable DC current level is 1% of inverter rated current.
Germany	DIN VDE 126 [18]	DC sensitive residual current device required. Disconnection required if a step of 30 mA or larger within 1 s occurs, or the continuous residual current exceeds 60 mA per kVA or inverter rated power. DC injection detection device with inverter disconnection is required for transformerless inverters. Detection threshold is 1 A.
Spain	RD 1663/2000 [6]	No limits.
Australia	AS 3300 [19]	DC current not to exceed 5 mA. Guidance form AS3300 50 Hz transformer interface between DC and AC preferred transformerless inverters must have DC injection detection device.
The United Kingdom	G83 England G77 [20]	Use of an isolation transformer is recommended. A DC injection detection device with inverter disable is required for transformerless inverters, the maximum DC current limit is 5 mA.

and the United Kingdom, where the PV industry of connection to the network has experienced remarkable growth, in the last 10 years, summarized in Table 2.

Regarding the data it is possible to infer that discrepancies exist between the standards that are applied in the different countries. For exampl, in three of the countries analyzed (the USA, Japan and Australia), limitations are imposed with respect to the DC injection of the CC for inverters with transformer. Only Australia imposes an absolute limit (5 mA), for this type of inverters. However, Japan and the USA establish a percentage limit, which oscillates between 0.5% for USA and 1% for Japan, depending on the power of the

Table 3
Maximum DC current permitted in DC/AC inverters, according to mandatory specific standards of each country

Country	Max DC current permitted with transformer	Max DC current permitted without transformer
USA [13]	0.5% rated power inverter	0.5% rated power inverter
Japan [17]	1% inverter rated power	1% inverter rated power
Germany [18]	—	1000 mA
Spain [6]	—	—
Australia [19]	5 mA	5 mA
The United Kingdom [20]	—	5 mA

inverter. Nevertheless, in five of the six analyzed countries (with the exception of Spain) current limitations are imposed for transformerless inverters. In this case, three of the five countries impose absolute limits (Germany, Australia and the United Kingdom), whose range varies between 1000 and 5 mA; and two countries (USA and Japan) establish percentage limits which are the same as those for the inverters with transformers (Table 3).

Besides analyzing mandatory specific standards of each country, seven general international standards have been analyzed which are recommendations, established by the country of origin. Such standards are summarized in Table 4. As can be observed, some of the said standards are in fact of obligatory compliance in origin countries, such as DIN VDE 126 of Germany or Standard IEEE 929-2000, from the USA. Of these standards, three come from the USA (two from IEEE and one from UL) and three from Europe (IEC) and one from Germany (like DIN norm). In all of them, except in the CEI 61000-2-2:2002 norm and IEC Standard EN61000-3-2, DC limitations are given, for all type of inverters. Only the German norm imposes an absolute limit (1 A for transformerless inverters) whereas the rest imposes limits referring to the nominal power inverter (which oscillates between 0.5% and 1%). In addition, it is possible to mention that although CEI 61000-2-2:2002 affirms that perhaps inverters can inject DC current in the network, it is assumed that this value is variable and it will be necessary to study it case by case.

5. Conclusions

Conditioned by the new incentives of each country, in recent years there has been an increasing interest in the use of low voltage small grid-connected PV systems connected to the public network. In those systems, an essential element is the inverter, that is, the element that DC voltage at PV generator converts to a sinusoidal AC current waveform, so that it may be connected and synchronized to the utility network. Nevertheless, that conversion must meet minimum quality criteria regarding the current of the overtones, the injection of CC, and the factor of power. Indeed, this work has studied the legislation of PV inverters related to the DC injection, in the AC side. This has been done by means of a compilation of the information, referring exclusively to the injection of DC, of the PV systems of low tension connected to the network, as well as the international standards such as the effective legislation in six countries (USA, Germany, Japan, Spain, Australia and the United Kingdom), where the PV industry of connection to the network has experienced remarkable growth in the past 10 years.

Table 4
Seven general international standards, which are recommendations, established by the country of origin, where DC injection is mentioned

Come country	Standards and guidelines	
GERMANY	DIN VDE 126 [18]	Limits for DC injection into AC grid DC injection detection device with inverter disconnection is required for transformerless inverters. Detection threshold is 1 A.
USA	IEEE Standard 929–2000 [13]	Inverter manufacturers generally use one of two methods to prevent the injection of DC current into the utility interface. One method is to incorporate an AC output isolation transformer in the inverter. The other method, which uses a shunt or DC-current sensor, initiates inverter shutdown when the DC component of the current exceeds the specified threshold. The PV system should not inject current >0.5% of rated power inverter ground output current into the AC interface under either normal or abnormal operation conditions.
USA	UL1741 [21]	A utility-interactive inverter shall not inject DC current into the AC output greater than 0.5% of the rms value of the rated inverter output current when the inverter is connected is connected to its rated DC supply and a simulated utility source.
USA	IEEE 1547 [22]	The DR (distributed resources and its interconnection system shall not inject DC current greater than 0.5% of the full rated output current at the point of DR connection.
EUROPE	IEC61727 [12]	Less than 1.0% of rated output current.
EUROPE	CEI 61000-2-2:2002 [23]	While a significant level of DC component is not normally present in the voltage on public power supply systems, the connection of certain non-symmetrically controlled loads could bring about this phenomenon. Geomagnetic storms have been found occasionally to give rise to large DC currents and voltages in some locations, but such uncontrollable events are not taken into account in this standard. In the event that a DC component is present in the supply voltage, a DC current can cause unsymmetrical magnetisation in distribution transformers, leading to overheating. Moreover, in flowing through the earth, such a current leads to increased corrosion of metal fixtures underground. The value of this current is quite variable, since it is determined by the DC resistance of the circuit concerned as well as by the voltage of the DC component. Therefore the tolerable DC voltage can only be determined case by case.
	IEC Standard EN61000-3-2 [24]	There are no limits placed on DC current injection defined in this standard. Additionally, under Clause 7, items with a rated power of less than 75 W do not have any harmonic emission limits at all. There are many devices that could potentially come under this DC injection caveat, including switch mode power supplies for domestic use and mains powered mobile phone charging units. These devices may cause cumulative harmonic pollution. It is recommended that a selection of Class D devices be tested to directly determine if there is any DC component and to quantify it.

From said legislation it has been possible to determine that discrepancies exist among the standards which are applied in the different countries. For example, in three of the countries analyzed (USA, Japan and Australia), limitations with respect to the injection of

the CC are imposed for inverters with a transformer. Only Australia imposes an absolute limit (5 mA), for this type of inverters. However, Japan and USA establish a percentage limit which oscillates between 0.5% for the USA and 1% for Japan, depending on the rated power inverter. Nevertheless, in five of the six analyzed countries (with the exception of the case of Spain), three of five countries impose absolute limits (Germany, Australia and the United Kingdom), whose range varies between 1000 mA to 5 mA; and two countries (USA and Japan) establish percentage limits for inverters with transformers.

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